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A Field Study of Thermal and Visual Performance of Self-Shading Energy Commission Diamond Building, Putrajaya, Malaysia

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Abstract

Objectives: This study investigates daylighting condition and cooling effects of a self-shading Energy Commission Diamond building in Putrajaya, Malaysia, using field measurements. **Methods/Statistical Analysis:** The field data were collected using a HD35ED series data logger measuring instrument with a HD35AP base unit. **Findings**: The results from the field measurement indicate that illuminance in the building resulting from daylighting alone are above 200 Lux. The average daylight factor is 2.7% which is within the acceptable range of indoor illuminance. From the calculations of OTTV, it is clearly shown that there is reductions of heat transfer into the Diamond building due to it incline wall facade that provide self-shading on the building. The average amount of sensible heat energy within the building is 45.8 KJ/Kg, with the west wing and the south wing indoor office spaces having a difference of about 1.5 KJ/Kg in their enthalpy. On an average, there is a total reduction of 30.6 KJ per unit volume of heat gain into the Diamond building based on the enthalpy change. Considering occupants comfort and wellbeing in the building, the daylighting requirements and heat gain in the building are acceptable. **Applications/Improvement:** This result is an indication that self-shading in buildings provides efficient daylighting and cooling which in turn reduces the building energy consumption.

Keywords: Daylighting, Energy Commission Building, Self-Shading, Thermal Performance

1. Introduction

Building sustainability and energy efficiency have become an important issue of discourse which requires much attention to be committed to it[1]. Buildings have been ascertained to be one of the highest in energy consumption especially in nations whose level of urbanization and standard of living is high[2,3]. In the tropical climate of Malaysia, most of the energy consumed is used for cooling. In a study conducted by[4], it was shown that of the total energy consumed by a tropical office building in Malaysia, a higher percentage of 64% is for air-conditioning only. The remaining 36% is consumed for general equipment and lighting at 24% and 12% respectively. This is in contrast with[5] who asserted that, air conditioning systems and lighting use 57% and19% of energy consumption in building respectively in Malaysia. He further stated that, lift and pumps consume 18% while other equipment consumes 6% of energy consumption in buildings in Malaysia. However, the outcome of these studies is an indication for the needs to reduce energy consumption in Malaysia by applying energy efficient strategies. It has been ascertained that the application of innovative energy efficient design of buildings have the advantage of reducing total energy

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consumption of a building[6]. Due to the high cost of energy and its environmental impact, energy consumption in buildings needs to be reduced both at the building conceptual design stage and the building in use. Both passive and active design measures can be incorporated in a building design in order to achieve energy efficiency and environmental sustainability. In[6] made evident the need to perform building simulation and modelling for energy efficiency especially at the design stage in order to achieve sustainable green buildings.

Self-shading strategy is one of the passive solar strategies to reduce incidence of direct solar radiation on building facade which causes heat gain reduction in buildings in tropical climate of Malaysia[7]. Building envelope is the exterior portions of a building through which thermal energy is transferred. The building envelope has to block out heat gain into buildings via conduction and solar radiation[8].

Solar heat gain into a building is affected by the building shading and window size, which in turn influences the amount of cooling it required in the building[9]. Shading device design is based on the incident solar radiation, incident angle and window area. According to[10], only a fraction of the amount of sun rays incident on a wall is transmitted through building fenestration. The intensity of solar radiation incident on horizontal surface is 1000 W/m^2 in a year while that incident on a vertical wall surface with East and West orientation is 850 W/m^2. North and South window facing orientation is preferable especially in the tropical regions to reduce the effect of solar radiation[11]. This orientation still allows for better illuminance in the building. In Malaysia, the optimum window area requirement for natural daylighting in a building is 25% of the wall area[12], while an experimental measurement of the Energy Commission Building in Malaysia provided a WWR of 60% for the building[13]. Window Wall Ratio (WWR) plays an important role in building cooling and lighting. For both cooling and lighting, a WWR of 25% is the optimum requirement[12]. A WWR that is optimum for energy efficiency may not provide the required daylighting in a building.

Different efforts have been made towards constructing buildings that are refer to as "Zero Energy Building (ZEB)" in order to promote zero energy cities planning[14]. Some of the most important issues that required special attention in building design and construction are the requirements for energy efficiency and acceptable sustainable options[1]. Thermal and lighting loads are major contributors to energy consumptions in buildings. It has been ascertained that about 52% of energy consumption in office buildings is accounted for by air-conditioning[4]. In Malaysia, energy consumption is mostly for air conditioning because of its hot and humid climate. Out of about 250 KWh/m^2 consumed annually in a typical Malaysian office building, air conditioning takes about 64% while the remaining 36% is shared between lighting and general equipment in the ratio of 1:2 respectively[4].

The demand for energy outweighs the supply of natural resources which has resulted into the rising cost of energy. Consequently, energy consumption has attracted a lot of attention not only for its environmental impact, but also its rising cost. The design and construction of buildings towards achieving environmental sustainability have therefore been encouraged through the large-scale application of relevant strategies and technology. According to[15], a reduction in energy demand and consumption can be achieved firstly, through user-based approach and secondly through infrastructure-based based approach. The first approach involved a modification of a building occupant's behaviour towards decrease in demand in terms of functional output, while the second approach is design of buildings whose operational function require less energy. Passive design techniques could therefore result into improve natural ventilation and thermal insulation in buildings.

Different studies have been undertaken in Malaysia for instance, towards developing ways of reducing annual energy consumption for cooling in office buildings[16–18]. Also, available literature have shown that the design of buildings by architects is mostly centred on aesthetic values rather than the climate situation and energy savings[19]. A form of self-shading in buildings have been seen as one of the ways the impact of solar radiation in high-rise buildings can be reduced[7,20].

Optimum geometry of external shading devices has been investigated in Malaysia by[21]. Furthermore the effect of internal shading devices has been studied in Malaysia by[22]. Daylighting advantage in buildings can be enhanced as a means of utilizing solar energy through improved building shading[23]. However, heat gain with respect to building external shading cannot be considered in isolation of daylighting as a basic requirement in office buildings. There is a relationship between heat gain in buildings and daylighting. Heat gain into a building through solar radiation can be reduced by the use of shading device on the building. However, the use of shading devices on a building can also affect the amount of daylighting into the building. The effectiveness of a building shading device should be such that it enhances both heat gain and daylighting requirement of the building. Where there is more heat gain into a building through sunlight harvesting for daylighting, there will be increase in energy consumption for cooling and less for lighting. On the other hand, in reducing the amount of heat gain through the introduction of solar shading device on the building, there will be an increase in energy consumption for lighting.

This study therefore seeks to investigate daylighting and cooling effects in a self-shading Energy Commission building located in Putrajaya, Malaysia, using field measurements data collected from the building. The result of the field measurement will be analysed empirically in order to determine the effectiveness of self-shading facade design configuration and criteria as one of energy efficient design strategies for tropical office buildings.

2. Installation of Equipment and Measurement

In measuring daylight parameter of a Building, the first task to be performed was to calculate the room index in order to know the numbers of devices required for accurate measurement[24]. However, this will require measuring the room geometry which includes the room area, length, width, mounting height and so on Table 1. Then, set date, start time and time interval of 10 minutes between each record. It is followed by connection of data logger to the illuminance sensor. Wall Plane Illuminance (WPI) is determined to be 900 mm which is equal the mounting height. The next step is to place the numbers of interior devices accordingly on the WPI and the exterior device is mounted on the roof top devoid of any blockage for accurate exterior readings. The recording commences by pressing the 'log' button.

Two different orientation (south and west) office rooms were selected for this study because of their high exposure to solar radiation most especially the west facing[25–29]. An office room was chosen from each orientation for data collection and measurement. All geometrical dimension of the two offices were measured as previously mentioned and their orientation was determined by compass. The measured room geometry was used to calculate the room index of each room to determine the required numbers of daylight devices. Below, is the formula for evaluating the room index:

$$\text{Room index} = \frac{wl}{h(w+l)} \qquad \text{Equation (i)}$$

Where:
w = room width,
l = length of the room,
h = mounting height

Smith et al. (1983) and Shadwick J. (1984) defined mounting height as the vertical distance from the working plane to the luminaire. Smith proposes the room index from the calculation of various room area, Table 2 illustrates the minimum required number of daylight devices or points of a particular room.

Therefore, for a room with dimensions: $w = 5$ m, $l = 6$ m and $h = 1$ m

Room index $= \frac{30}{11} = 2.7$, hence the number of required points is 16 from Table 2. While the room with dimensions: $w = 3$ m, $l = 4.8$ m and $h = 1$ m will be:

Room index $= \frac{14.4}{7.8} = 1.8$ therefore, the required points is 9.

Table 1. Room Measurements and Geometric Features

Room orientation	Floor Level	Window Height (mm)	Sill Height (mm)	Window Orientation	Ceiling Height (mm)	Geometry (W x L x H) (mm)	Ceiling projection (mm)
south	6	2150	900	West (N10°)	3600	6000 x 5000 x 3600	1700
west	6	2150	900	South (E10°)	3600	4800 x 3000 x 3600	1700

Table 2. Room index and Number of points for work plane illuminance measurement (Smith et al, 1983).

Room index	number of points (devices) for measurement
<1	4
>1 and < 2	9
>2 and < 3	16
>3	25

2.1 Work Plane Illuminance

Work plane illuminance is the quantity of illuminance suitable for a particular task in a particular point in a room space[30–32]. It is therefore one of the parameters for daylight evaluation as different points in a room has different standard of illuminance for a certain task. For instance, MS 1525[8] and CIBSE[33] accepted the range of 300-500 Lux for reading and writing task in an office room.

Similarly,[34]opined that a dark work plane illuminance for paper and computer work is the one less than 100 Lux. While the one between 100 Lux and 300 Lux is suitable for computer work and the preferred work plane illuminance for paper works range from 300-500. On the other hand, a work plane illuminance of 500 Lux causes visual discomfort for computer task.

2.2 Daylight Factor

Daylight factor expresses the level of illuminance quality of a space and is the ratio of mean interior illuminance to the mean illuminance of exterior as illustrated in the Equation below:

$$\mathbf{DF} = \frac{\boldsymbol{II}}{\boldsymbol{EI}}\ \mathbf{X\ 100}$$

Where: DF = Daylight Factor, II = Interior Illumination and EI = Exterior Illumination.

3. Method

This study involves empirical field measurement which was used in obtaining data in Energy Commission Diamond building, located at Putrajaya, Malaysia. The data were collected for seven days between the hours of 0800 to 1700 on 4 to 11 November 2014. Malaysia located along the equatorial lassitude areas is characterised with a uniform temperature and a relatively high humidity all through the year and a copious rainfall. A seven days weather forecast of Putrajaya gave an average daily temperature range of 25-33^{o}C (http://www.theweathernetwork.com/my/weather/wilayah-persekutuan-putrajaya/putrajaya).

The Energy Commission Diamond building is designed and constructed to as a piece to demonstrate the potentials of green buildings and sustainable environment. According to[3], this building is incorporated with innovative and building features for sustainability and energy efficiency. Empirical measurement was used for recording the required environmental parameters for this study in selected office rooms in Energy Commission's Diamond building to show the effect of inclined wall strategy on these parameters.

This study was carried out on the west and south wings of Diamond building. One office room space on each wing was chosen as location points for data collection and measurement. The equipment used for collecting data in the Diamond building is:

- HD35ED series data logger with a HD35AP base unit.
- Lux-meter sensor; LP471 PHOT Probe-vision 0.01 Lux-200.103 Lux for measuring outdoor illuminance level.

The HD35ED series data logger device has built-in sensors for measuring temperature, relative humidity, dew point, vapour pressure, mixing ration, absolute humidity and wet bulb temperature. The HD35ED data logger can be connected to a Personal Computer (PC) through the HD35AP based unit and an installed HD35AP-S software which allows database access of recordings from the data loggers. The physical quantities acquired/measured through the data loggers can be viewed in real time on PC screen. The measurement units can be set and configure through the base unit.

The office room geometry was measured to identify location for installation of data loggers. Four (4) data loggers were installed in each of the office room. The recordings for measurement in the office rooms were taken between 8.00 am and 5.00 pm in the west wing and the south wing. However, office furniture and partition were not considered to be of significant effect of daylighting condition in the study building. The data measurement for this study was carried out in an open office room.

Daylight Factor (DF) which is the percentage of the ratio between internal illuminance and external illuminance at a given time is determined as performance indicator for daylight efficiency in a room. For acceptable indoor illuminance, daylight factor should be between 2% to 5%[34]. Daylight Factor greater 6% can be problematic as it can result into glare and thermal problems[8]. An acceptable illuminance level for offices work plane ranges from 300 – 500 Lux, while an interior light intensity less than 100 Lux is not enough for a working environment[34]. A range from (100 – 300) Lux can only be proper when working on a computer or a self-illuminating object but not for general work environment that requires other activities[34]. The amount of heat gain during the period of measurement was calculated using psychometric chart.

4. Results and Discussion

The variations in the indoor environmental variables measured in the office space on the two wings of the Diamond Building are shown in Figure 1. These measurements were taken at a height of 1 m above the floor level. The external environmental conditions were measured at the roof top of the building. This building's roof top is an insulated concrete green roof that reduces heat absorption and also serves as a base for water harvesting tanks and installed solar panels (Figure 2). The outdoor measurement at the roof top space represents the instantaneous ambient environmental condition required for this study. An outdoor temperature range of 35.4-37.2^{o}C was recorded during measurement on the West wing of the building while a range of 35.1-36.5°C was recorded for the South wing. Figure 3b shows the outdoor temperature variation which reaches a maximum peak of 36.5°C at about 1230 hrs. As seen also in Figure 3a, the indoor air temperature in the West wing of the building was about 12-13.6°C below the outdoor temperature as measured simultaneously. However, the difference between the indoor air temperature and outdoor air temperature was approximately 11-12°C, slightly lower than the difference on the West wing. The average outdoor air temperature recorded for the locations on the West and South wing of the building was 36.2°C and 35.9°C respectively, while the average indoor air temperature was 23.4°C and 24.3°C in the West and South wings of the building respectively. Despite the fact that the office locations on both wings of the building are air-conditioned, the slight variation in their air temperature may be as a result of the different orientation of the office location in the building and also time of measurement. The average outdoor air temperature recorded during the measurement on the South wing of the building was lower than that for the West wing, yet, the average indoor air temperature on the South wing is still higher than the indoor air temperature on the West wing. As a result of this, heat transfer from the external environment into the building is a little more with the South building orientation than the West orientation.

The average relative humidity recorded at the office locations on both wings of the building were within the normal range. The average absolute humidity which is 10.3 g/Kg is the same on both wings of the building. This equality may be due to the same shading configuration applied on both building facades. The relative humidity on the West wing ranged from 48-51 % while the relative humidity on the South wing was approximately within 48% (Figure 3c). There is no difference between the average wet bulb temperatures recorded for the office location on both wings. The wet bulb temperature on the West wing ranged between 16.4-16.9°C whereas, the wet bulb temperature on the South wing was between 16.6-16.9°C. The difference between the average outdoor wet bulb temperatures (24.9°C) recorded at the roof top and the indoor wet bulb temperature on both wings was approximately 8°C.

The illuminance level taken at the central location within the office spaces considered is presented in Table 1. The illuminance level on the West wing office space

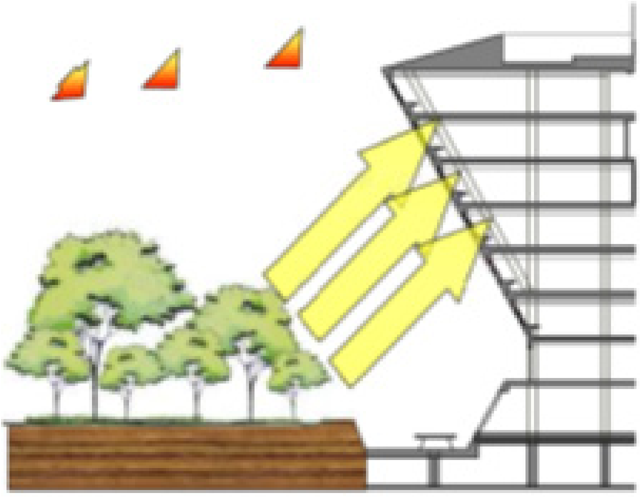
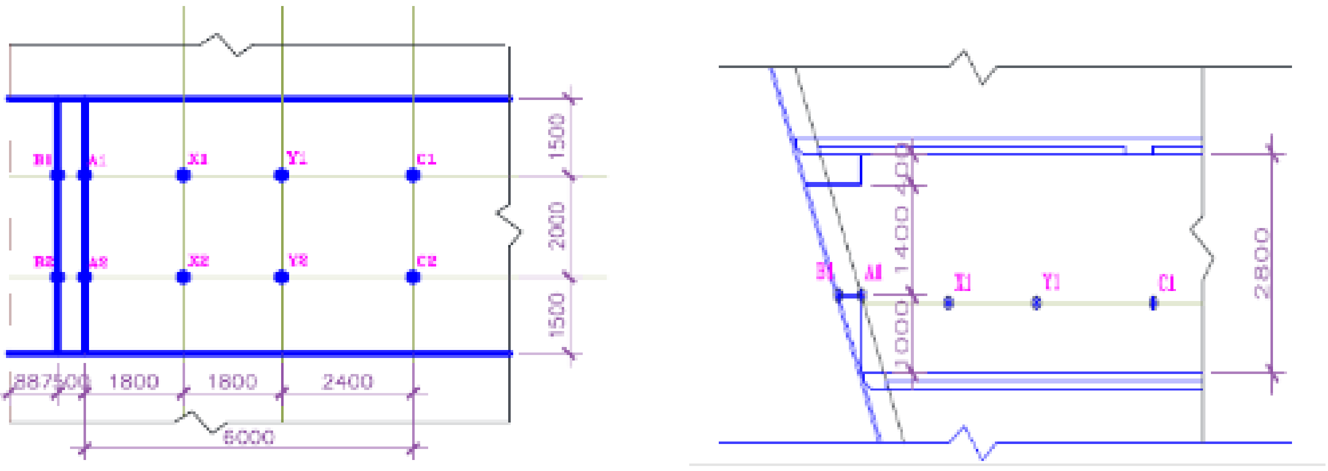
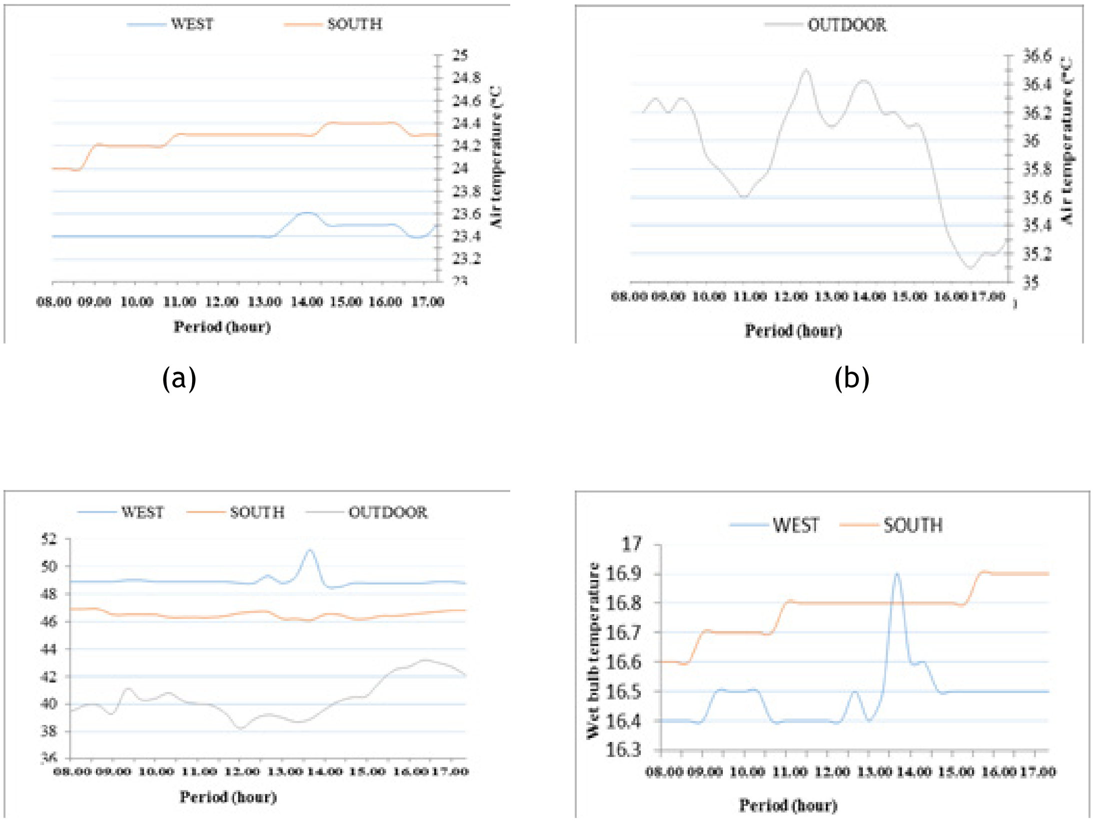


Figure 1. View of the case study building (a) external perspective (source: field photo); (b) sectional view (Source: Malaysia Energy Commission).



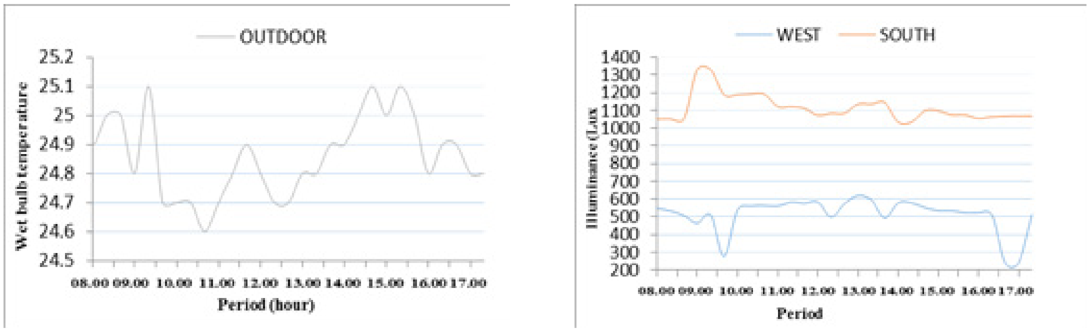
(a) (b)

Figure 2. Typical floor plan and section of west orientation office space selected for measurement.



(a) (b)

(c) (d)



(e) (f)

Figure 3. Variations of measured environmental variables in the building and the outdoors. Air Temperature (indoor); (b) Air Temperature (Outdoor); (c) Relative Humidity; (d) Wet Bulb Temperature. (Indoor); (e) Wet Bulb Temperature (Outdoor); (f) Illuminance.

Table 3. Work Plane Illuminance, when lights were off and on (Lux)

Points	X1	X 2	X 3	Y1	Y 2	Y 3	Z1	Z 2	Z 3	Ave
Southern Room	477.0	212.3	1062.6	370.8	265.0					
Western Room	477.0	212.3	612.9	249.7	265.0					

Table 4. WPI ratio

Southern Room	Western Room
0.20	0.35

Table 5. Average outdoor illuminance during measurement

Time	Average Outdoor Illuminance (Lux)
During measuring of south orientation	17817.0
During measuring of west orientation	18455.0

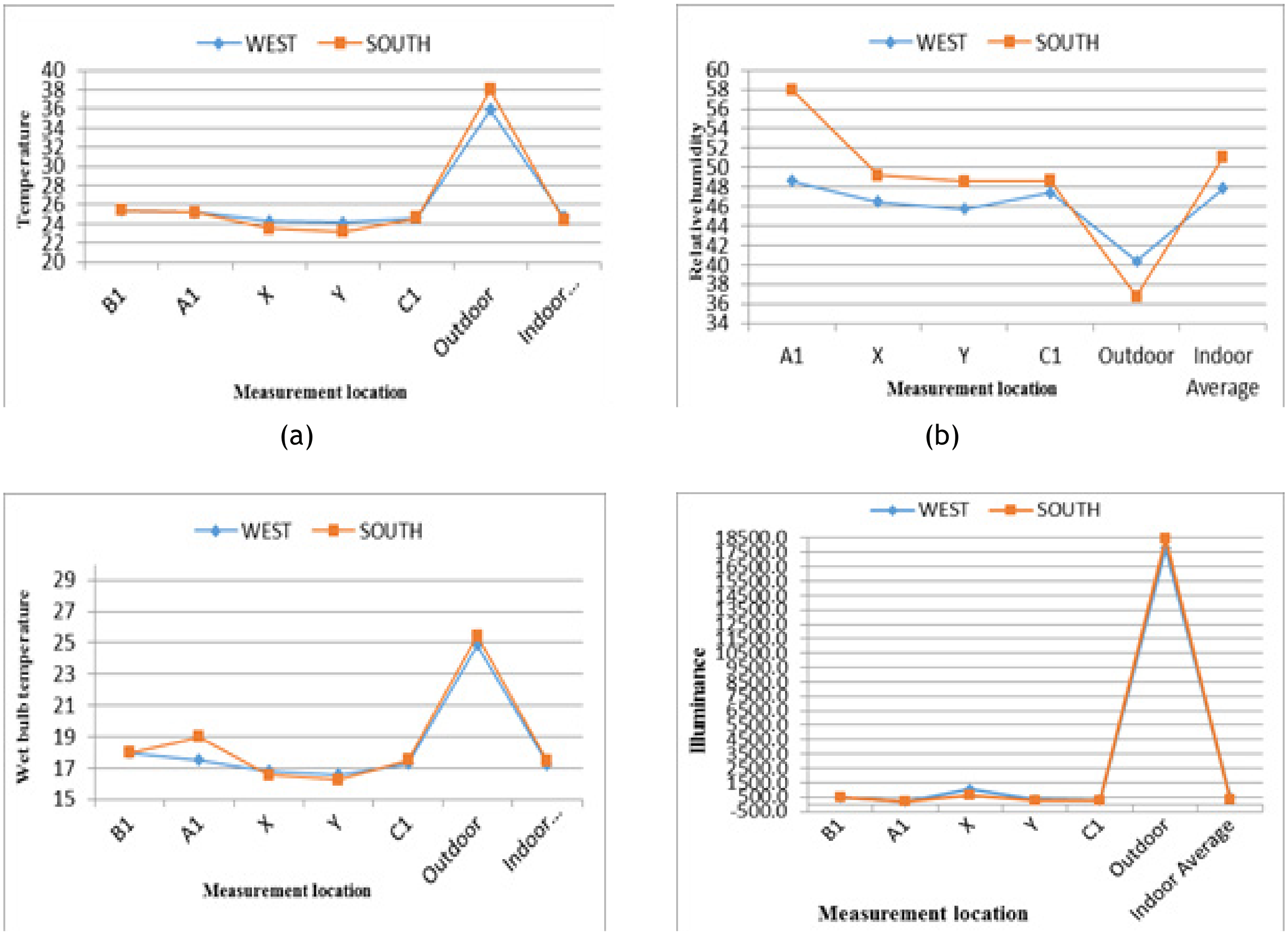
Table 6. Daylight factor for two measured rooms

Points	X1	X2	X3	Y1	Y2	Y3	Z1	Z2	Z3	Average
Southern Room	2.68	1.19	5.96	2.08	1.49					
Western Room	2.58	1.15	3.32	1.35	1.44					

ranged from 277-620 Lux with an average of approximately 534 Lux, while the illuminance level at the South wing office space ranged from 1052-1330 Lux with an average of approximately 1113 Lux. The average outdoor illuminance recorded at the roof top was approximately 18262 Lux, which gives a Daylight Factor (DF) of 2.9% and 6.0% in the office locations on the West and South wings respectively. The Daylight Factor in both office locations in the building provide acceptable level of illuminance for daylight performance, but the Daylight Factor on the South wing was above the range of acceptable indoor illuminance as recommended by[34]. However, the Malaysian standard[8] stipulated that illumination within a building becomes problematic when the daylight is above 6%. In Tables 3-6 work plane illuminance ranged from 277-620 Lux within the office location on the West wing is acceptable for both paper works and computer works whereas, the range of 1052-1330 Lux on the South wing is ideal only for paper work but too bright for computer works[8] as computers are self-illuminating. This could result into the problem of glare in the building. As shown in Table 1, the illuminance level of 477 Lux and 212.3 Lux was recorded at location B1 and A1 respectively on both wings of the building. This range of illuminance level does not provide any discomfort glare to occupant's view as it's within the acceptable range for optimum performance. However, locations X on both wings of the Diamond Building recorded and average illuminance level of over 600 Lux. This level of illuminance is an indication of visual discomfort to occupant's view.

4.1 IDaylighting Variations in the Building

As stated earlier, the Daylight Factor at the South wing of the building is quite higher than the Daylight Factor at the West wing as recorded. The measured data in Table 1 shows that the average illuminance level recorded at measurement points B1, A1 and C1 are the same for the office locations on both wings of the building. A higher average illuminance level of 1062.6 Lux and 370.8 Lux was recorded at points X and Y respectively in the South wing location while on the West wing of the building, the illuminance level recorded at points X and Y are 612.9 Lux and 249.7 Lux respectively. The higher illuminance level recorded at point B1 as compared to A1 was due to the direct incidence of sunlight on the glazed window area. The highest illuminance level was recorded at X in both office locations at the two wings of the building (Figure 4a). That level of illuminance was achieved at point X as a result of the split window design for the building exterior facades and the internal light shelf provided. The incident natural light from the sunlight are been redirected by the internal light shelf, thereby increasing the illuminance level at point X as compared with other locations within the same office space. The effect of the internal light shelf was more on the South wing of the building than the West wing as seen in the significant difference of illuminance level (449.7 Lux) recorded at point X.



(a) (b)

(c) (d)

Figure 4. Average parameters measured in different points within the office spaces (a)Temperature; (b) Relative Humidity; (c) Wet Bulb Temperature; (d) Illuminance.

4.2 Transfer of Heat and Reduction in Diamond Building According to MS 1525

The Application of self-shading strategy can lead to reduction of Overall Thermal Transfer Value (OTTV) in Diamond Building as this strategy provide shades that can cushion down the effect of heat in the building. The OTTV reduction can be calculated by its equation. Therefore, the quantity of the total heat gained by the inclined wall is compared with the bared wall façade of the building which has no shading strategy. In solving problem using OTTV equation, some parameters such as WWR, CF and SC are crucial. The determined values of the parameters were substituted in the OTTV equation and sometimes some of these parameters could be neglected in determination process because they are in the same parametric form such as absorptivity (α), area of wall, Uw and Uf were the same in both the Diamond Building and the conventional one[13].

Malaysia standard (1525) has illustrated the solar Correction Factor (CF) of the Diamond Building in various orientations as shown in Table 7. Consequently, the value of the North orientation is 0.9 while that of South orientation is 0.92. On the other hand, the values of East and West directions respectively are 1.23 and 0.94.

From the field measurement experience, the WWR of the façade is 100% because is completely glazed from the outside while the internal view revealed a WWR of 60% due to some lintels, beams and walls that reduces the windows' areas of the Diamond Building. Consequently, WWR of 60% is going to be used in the OTTV calculations.

It should be noted that in considering conventional building or building that provide no shade, the solar coefficient is considered to be unity or 1. Now to evaluate the OTTV of building with no shade, the equation below is adopted:

$$OTTVI = 15\ \alpha\ (1-WWR)\ Uw + 6\ (WWR)\ Uf + (194 \text{ x } CF \text{ x } WWR \text{ x } SC)$$

OTTV of the north facade is represented by OTTVN

$$OTTVN = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 0.90 \times 0.6 \times 1)$$

$$OTTVN = 6\ \alpha\ Uw + 3.6\ Uf + 104.76$$

OTTV of the South façade is represented by OTTVS

$$OTTVS = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 0.92 \times 0.6 \times 1)$$

$$OTTVS = 6\alpha\ Uw + 3.6\ Uf + 107.08$$

OTTV of the East façade is represented by OTTVE

$$OTTVE = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 1.23 \times 0.6 \times 1)$$

$$OTTVE = 6\ \alpha\ Uw + 3.6\ Uf + 143.172$$

OTTV of the West façade is represented by OTTVW

$$OTTVW = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 0.94 \times 0.6 \times 1)$$

$$OTTV\ W = 6\ \alpha\ Uw + 3.6\ Uf + 109.416$$

Complete heat transfer of the whole building is represented by OTTV.

$$OTTV = [An \times OTTVn + As \times OTTVs + Ae \times OTTVe + Aw \times OTTVw]/[An + As + Ae + Aw]$$

$$OTTV = A[(6\alpha Uw + 3.6Uf + 104.76) + (6\alpha Uw + 3.6Uf + 107.08) + (6\alpha Uw + 3.6Uf + 143.172) + (6\alpha Uw + 3.6Uf + 109.416)]/[4(A)]$$

$$OTTV = A\ [(18\ \alpha Uw + 10.8\ Uf + 464.42)]/4A$$

Finally total heat transfer of the building is: $OTTV = [(18\ \alpha Uw + 10.8\ Uf + 464.42)]/4$

Presume that all parameters are considered equal for conventional building but Shading Coefficient that is related to shading strategy is not considered equal. The subsequent section shows the calculation of Shading Coefficient for Energy Commission's Building. Whereas wide of horizontal projection in Energy Commission's Building is equal to 1.70 m for each level and window height is 2.15 m. Hence the ratio of width of horizontal projection per height of fenestration which is specified as the ratio R1 is 0.8 for Energy Commission's Building. Tables 8 and 9 shows that Shading Coefficient for North and South direction is equal to 0.67, in addition Shading Coefficient for West and East are 0.65 and 0.6 respectively.

For the value of OTTV of Diamond Building as a self-shaded building, the calculation is shown below using the above Shading coefficient as shown in Table 2 instead of a single one for all the orientations:

OTTV of the north self-shading façade is represented by OTTVNs

$$OTTVNs = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 0.90 \times 0.6 \times 0.67)$$

$$OTTVNs = 6\alpha\, Uw + 3.6\, Uf + 70.18$$

OTTV of the south self-shading façade is represented by OTTVSs

$$OTTVSs = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 0.92 \times 0.6 \times 0.67)$$

$$OTTVSs = 6\alpha\, Uw + 3.6\, Uf + 71.74$$

OTTV of the east self-shading façade is represented by OTTVEs

$$OTTVEs = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 1.23 \times 0.6 \times 0.6)$$

$$OTTVEs = 6\alpha\, Uw + 3.6\, Uf + 85.90$$

OTTV of the west self-shading façade is represented by OTTVWs

$$OTTVwss = 15 \times \alpha \times (1 - 0.6) \times Uw + 6 \times (0.6) \times Uf + (194 \times 0.94 \times 0.6 \times 0.65)$$

$$OTTVwss = 6a\, Uw + 3.6\, Uf + 71.12$$

OTTV of the whole self-shading envelop of the building is represented by OTTVb

Table 7. Average measurement of environmental variables in different office space

	Temperature (°C)		Relative humidity (%)		Wet bulb temperature (°C)		Illuminance (lux)	
Measurement location	**South**	**West**	**South**	**West**	**South**	**West**	**South**	**West**
B1	25.4	25.4	51.1	51.1	18	18	477.0	477.0
A1	25.2	25.2	48.6	58	17.5	19	212.3	212.3
X	24.3	23.5	46.5	49.2	16.8	16.6	1062.6	612.9
Y	24.2	23.2	45.7	48.5	16.6	16.2	370.8	249.7
C1	24.6	24.6	47.4	48.6	17.3	17.5	265.0	265.0
Outdoor Average	35.9	38.0	40.4	36.7	24.9	25.4	17817.0	18454.7
Indoor Average	24.7	24.4	47.9	51.1	17.2	17.5	477.5	363.4
Daylight Factor							2.6%	2.0%

Table 8. Malaysian Standard MS1525: (2007) Solar correction factor

Direction	North	Northeast	East	Southeast	South	Southwest	West	Northwest
Correction Factor	0.90	1.09	1.23	1.13	0.92	0.90	0.94	0.90

Table 9. Shading coefficient for various orientations (MS1525: (2007))

	Orientation				
R	North/South	East	West	Northeast Southeast	Northwest Southwest
0.3-0.4	0.77	0.77	0.79	0.77	0.79
0.5- 0.7	0.71	0.68	0.71	0.69	0.72
0.8-1.20	0.67	0.60	0.65	0.63	0.66
1.30 -2.00	0.65	0.55	0.61	0.60	0.63

$$OTTV\ b = [An \times OTTVn + As \times OTTVs + Ae \times OTTVe + Aw \times OTTVw]/[An + As + Ae + Aw]$$

$$OTTVb = A[(6\alpha Uw+3.6\ Uf+70.18)+(\ 6\alpha\ Uw+3.6\ Uf+71.74)+(\ 6\alpha\ Uw+3.6\ Uf+85.90)+(\ 6a\ Uw+3.6\ Uf+71.12)]/[4(A)]$$

$$OTTVb = A[(18\alpha Uw+10.8Uf+298.94)]/4A=[(18\ \alpha Uw+10.8\ Uf+298.94)]/4$$

From the two calculations, it is clearly shown that there is reductions of heat transfer into the Diamond building due to it incline wall facade that provide self-shading on the building. Therefore, from the two calculations, (18 αUw+10.8 Uf) appears in both evaluations therefore can be neglected such that the non-shaded and self-shaded building solution can represent (464.42/4) w/m^2 and (298.94/4) w/m^2 respectively. However, heat gained by each building form is finally 116.105 w/m^2 and 74.735 w/m^2 respectively. To determine the heat reduction by the Diamond building the difference between the non-shaded (OTTV) and self-shaded (OTTVb) buildings is calculated thus:

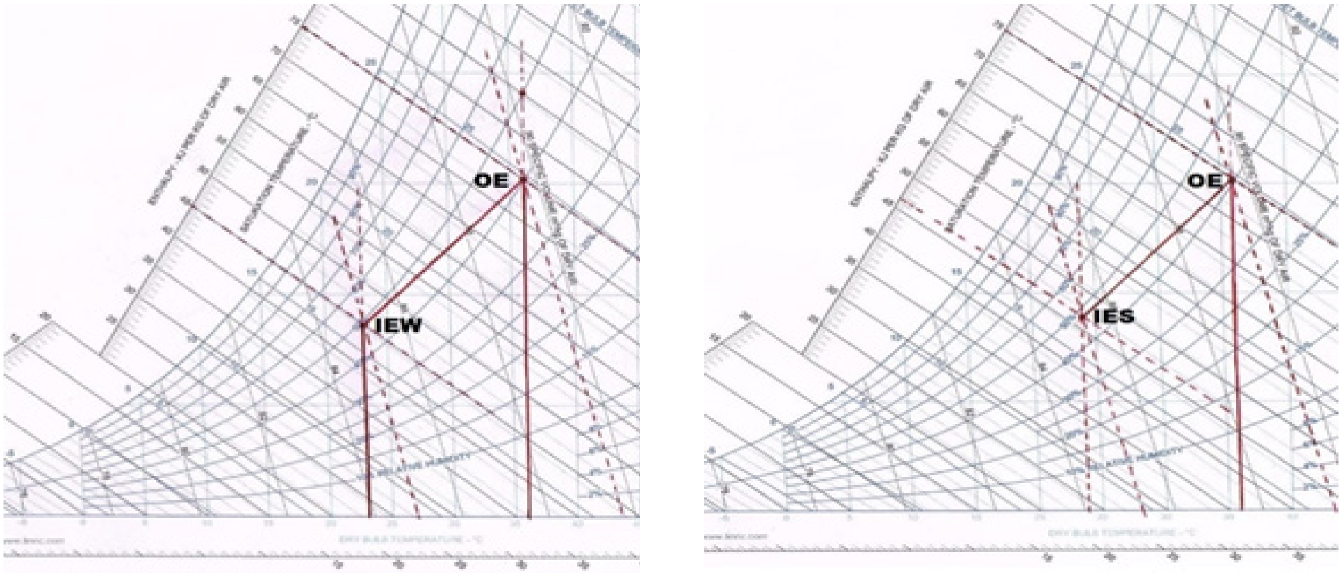
$$OTTV\text{-}OTTVb = (116.105\ -74.735)\ w/m^2 = 41.37\ w/m^2.$$

It implies categorically that, 41.37 w/m^2 of heat transfer was reduced by the self-shading strategy of the Diamond building.

4.3 Heat Gain Variations in the Building

The heat gain into the building is determined using the psychrometric chart. This heat gain depends on the heat energy in the air within the building due to sensible (temperature) and latent (moisture) heat. The average measurements for the purpose of application with the psychrometric chart are approximated to the nearest whole number figure. The determination of the heat gain is based on the relationship between the average outdoor relative humidity and temperature and the average indoor relative humidity and temperature as measured in the building. The heat gain or loss is the difference between the outdoor enthalpy and the indoor enthalpy[35]. The average outdoor relative humidity and air temperature for both West and South wings of the building is approximately 40% and 36°C respectively. The average indoor relative humidity and air temperature for the West wing is 49% and 23°C respectively whereas the average for the South wing is 47% and 24°C respectively.

From the psychrometric chart (Figure 5), the Outdoor Enthalpy (OE) recorded at 40% relative humidity and 36°C temperature is 75 KJ/Kg. The Indoor Enthalpy (IEW) recorded from the psychrometric chart at 49% relative humidity and a temperature of 23°C is 45 KJ/Kg (see Figure 5a) on the West wing of the building while the Indoor Enthalpy (IES) recorded at 47% relative humidity and 24°C on the South wing is 46.5 KJ/Kg (see Figure 5b). The specific volume of dry air is approximately 0.89 m^3/Kg and 0.85 m^3/Kg for the building's outdoor and indoor respectively as determined on the psychrometric chart for both West and South wings of the building. Heat loss or gain is equal to a change in enthalpy, therefore, the radiation heat that was shielded by the building envelope is 30 KJ/Kg on the West wing and 28.3 KJ/Kg on the South wing. The total heat energy reflected and/or absorbed from penetrating into the building is equivalent to the change in ratio of the enthalpy to specific volume of dry air between the outdoor environment and indoor environment of the building. The specific volume of dry air is the same for both wings of the building therefore, the total energy screened from the building on the West wing is approximately 31.3 KJ per volume of dry air and 29.6



(a) (b)

Figure 5. Psychrometric chart for determining enthalpy, (a) West Orientation, (b) South Orientation.

KJ per volume of dry air in the South wing. This result is an indication that cooling effect of the building facade configuration performance is better at the West building orientation with heat energy reduction of about 2 KJ per volume of air more than the building's South-facing orientation. On an average, the Diamond building façade configuration is able to absorb and screened out from the building about 30.6 KJ of heat per unit volume of dry air.

5. Conclusion

The Diamond building is naturally lighted by diffuse sunlight while the direct solar radiation is shaded from entering into the building by inclined glazed wall facades. This diffused sunlight contributes little to indoor heat gain as compared to the direct incidence of solar radiation. The basic conclusion that can be drawn from this study may be summarized as follows:

- The indoor temperature in the Energy Commission Diamond building is influenced by the building orientation. The air temperature in the office space located on the building's south orientation is slightly higher than the air temperature of the office space located on the west wing with approximately 1^{o}C. The relative humidity on the other hand is higher only with about 2.5% in the West wing than on the South wing of the building, though they both fall within normal range.
- Illuminance in the building is generally above 200 Lux without artificial light. The self-shading principle and light shelf provided in the building enhanced more daylighting into the depth of the office spaces.
- Heat transfer from the external environment into the building is relatively reduced as the outdoor enthalpy is higher than the indoor enthalpy with about 29 KJ/Kg.

A relationship exists between the design of shading in buildings for heat gain reduction and daylighting. Solar radiation can be reduced by the use of shading devices; however, these shading devices would also affect the amount of daylight into the building. As such, the effectiveness of a shading device should be such that it reduces heat gain while providing the required amount of daylight into the building. Therefore, the self-shading principle of the Diamond building can be said to have enhanced the achievement of acceptable indoor natural daylighting and reducing heat gain as a result of the screening of direct solar radiation into the building spaces.

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